Science with the EXTraS Project: Exploring the X-ray Transient and variable Sky.

A. De Luca, R. Salvaterra, A. Tiengo, D. D'Agostino, M.G. Watson, F. Haberl, J. Wilms *on behalf of the EXTraS collaboration.*

Abstract The EXTraS project ("Exploring the X-ray Transient and variable Sky") will characterise the temporal behaviour of the largest ever sample of objects in the soft X-ray range (0.1-12 keV) with a complex, systematic and consistent analysis of all data collected by the European Photon Imaging Camera (EPIC) instrument onboard the ESA XMM-Newton X-ray observatory since its launch. We will search for, and characterize variability (both periodic and aperiodic) in hundreds of thousands of sources spanning more than nine orders of magnitude in time scale and six orders of magnitude in flux. We will also search for fast transients, missed by standard image analysis. Our analysis will be completed by multiwavelength characterization of new discoveries and phenomenological classification of variable sources. All results and products will be made available to the community in a public archive, serving as a reference for a broad range of astrophysical investigations.

A. De Luca
INAF-IASF Milano, Via Bassini 15, I-20133 Milano, Italy e-mail: deluca@iasf-milano.inaf.it

R. Salvaterra
INAF-IASF Milano, Via Bassini 15, I-20133 Milano, Italy e-mail: ruben@iasf-milano.inaf.it

A. Tiengo
IUSS Pavia, Piazza della Vittoria 15, I-27100 Pavia, Italy e-mail: andrea.tiengo@iusspavia.it

D. D'Agostino
CNR-IMATI, Via de Marini 6, I-16149 Genova, Italy e-mail: dagostino@ge.imati.cnr.it

M.G. Watson
University of Leicester, Department of Physics and Astronomy Leicester, LE1 7RH, UK
e-mail: mgw@leicester.ac.uk

F. Haberl
MPG-MPE, Giessenbachstrasse, D-85748 Garching, Germany e-mail: fwh@mpe.mpg.de

J. Wilms
ECAP, Sternwartstrasse 7, D-96049 Bamberg, Germany
e-mail: joern.wilms@sternwarte.uni-erlangen.de

1 The EXTraS project: aim, implementation.

The EXTraS project ("Exploring the X-ray Transient and variable Sky") will systematically explore the temporal domain information stored in the database collected by the European Photon Imaging Camera (EPIC, [12, 14]) onboard the ESA XMM-Newton observatory. EPIC is the most powerful tool to study faint X-ray sources in the 0.1-12 keV range. Indeed, the Serendipitous Source Catalogue based on EPIC data, listing more than 560,000 detections in its most recent release (3XMM, see [8]), is the largest catalogue of X-ray sources ever compiled. However, time-domain information in such data, although very rich, remained mostly unused. EXTraS will release to the community a full temporal characterization (both aperiodic and periodic variability) of hundreds of thousand of sources with flux spanning from 10^{-9} to 10^{-15} erg cm^{-2} s^{-1} (0.2-10 keV), on time scales ranging from ~ 0.1s to ~ 10 years. EXTraS will also search for short-duration transients, not included in 3XMM, and will also perform a phenomenological classification of all sources based on their temporal and spectral properties. The different lines of temporal analysis implemented within the project are described in more detail in [3].

The project has received funding within the EU-FP7 framework (grant agreement n. 607452) and is carried out by a collaboration including INAF (Italy), IUSS (Italy), CNR/IMATI (Italy), University of Leicester (UK), MPE (Germany) and ECAP (Germany). More information, updates on the project as well as a full list of contacts can be found by visiting the project web site at www.extras-fp7.eu.

2 An (incomplete) overview of Science with EXTraS.

The extremely broad range of variability timescales and luminosities investigated by EXTraS is shown in Figure. 1. The scientific discovery space is very large and we trust that EXTraS results will have a great impact in many areas of astrophysics and cosmology. The blind nature of our search will allow astronomers to measure (or give strong limits on) the intrinsic occurrence rate of different transient events and to perform population studies. Withouth demanding completeness, we include below a list of science cases that will benefit of our results (see also caption to Fig. 1).

Flaring stars: constraining, on a statistical basis, the duration, duty cycle and amount of energy released in flares of different stellar groups. Indeed, as an interesting first result of EXTraS, we may mention the unexpected detection of a flare from a *very young protostar* (Pizzocaro et al., submitted to A&A)

Cataclysmic variables and Novae: unveiling periodicities and bursts in about 100 known sources; searching for new systems.

Low-mass X-ray binaries (LMXBs): probing e.g. the properties of bursting LMXBs [11] – in particular, for the poorly known "burst only sources". Bursts from M31, the closest spiral galaxy, can also be detected[5].

High-Mass X-ray Binaries (HMXBs): constraining e.g. the census of Supergiant Fast X-ray Transients (SFXT) [9], which is crucial to unveil the evolutionary path
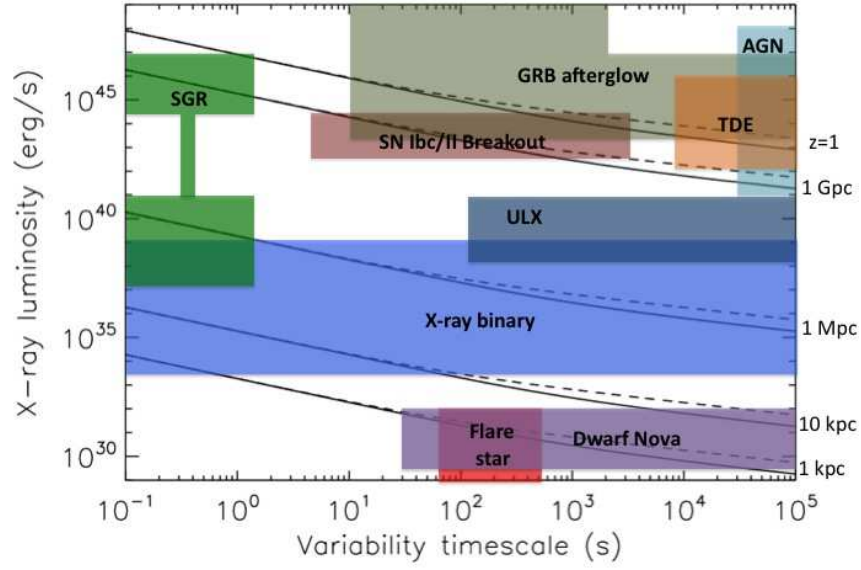
Fig. 1 Peak X-ray luminosity of different source populations as a function of their characteristic variability time scale (adapted from [7]). Diagonal lines mark the approximate EXTraS 0.5-2 keV sensitivities (at 4σ confidence, EPIC/pn camera only) for various source distances. Solid/dashed lines correspond to min/max particle background levels. Even assuming a very conservative 6.5σ sensitivity level (a factor 2–5 higher flux than in the figure), implying an essentially null contamination from spurious detections, we can expect a very rich harvest of variable sources, based on the equivalent sky coverage of EPIC data and on previous observational results and theoretical models. Among such sources, several hundreds of flares from a broad population of stars and protostars; 3-300 and 0.3-30 bursts from persistent and transient LMXBs, respectively, in the Galactic Center region; 3-5 SFXTs active in bright flaring and 40-75 sources in an intermediate state of flaring; several new magnetars; a few TDEs up to z$\sim 5-6$; up to a dozen low-luminosity GRBs up to z~ 2; about ten SN shock break-out events up to z~ 0.1; moreover, it can be estimated that about 100 "Fast Radio Burst" should have occurred within the field of an ongoing EPIC pointed observation.

and formation rate of massive stars.

Isolated Neutron Stars: constraining e.g. the population of magnetars (Anomalous X-ray Pulsars, AXPs, and Soft Gamma Repeaters, SGRs) [6] and its relation to the overall population of Neutron Stars (NS), which will also impact on our comprehension of the short GRBs. The case of GRB150301C/3XMM J004514.7+415035, with properties consistent with those of an active magnetar in M31, are a clear demonstration of the potentialities of EXTraS in this field (see GCN 17548 and ATel #7181).

ULtraluminous X-ray Sources (ULXs): assessing accretion physics in these poorly understood sources [4] by e.g. searching for, and unveiling, source "states"; systematically searching for bursts and periodicities (orbital, or rotational)

Tidal Disruption Events (TDEs): constraining their poorly known statistics (even

the case of no detections would be interesting) and their physics [1].

Gamma-Ray Bursts (GRBs): constraining the rate of Low-Luminosity GRBs (e.g. [2]), possibly up to high redshift, and their progenitors; no detections would set the strongest available constraint on their population.

Supernovae (SNe): inferring a measure of the SN rate independent from optical surveys by detecting SN shock breakout events [10]; no detections would set important constraints on the poorly known underlying physics.

Active Galactic Nuclei (AGN): measuring the mass of ~ 100 AGNs, based on their variability properties; calibrating the variability-luminosity relation locally; characterizing the variability of Blazars, their duty-cycle on short timescales and deriving constraints on particle injection/acceleration, magnetic field and BH mass.

Rare events: ranging from galactic events (e.g. TDEs of minor bodies falling onto NSs or BHs) to cosmic ones (e.g. orphan afterglows of GRB seen off-axis, GRBs from the first very massive stars); constraining the high energy properties of the puzzling "Fast Radio Bursts" [13].

Totally unexpected discoveries can be also foreseen, as has always been the case when a new region in parameter space has been explored.

References

1. Burrows, D. N., Kennea, J. A., Ghisellini, G. et al. (2011). Relativistic jet activity from the tidal disruption of a star by a massive black hole. Nature 476, 421
2. Campana, S., Mangano, V., Blustin, A. J. et al. (2006). The association of GRB 060218 with a supernova and the evolution of the shock wave. Nature 442, 1008
3. De Luca, A., Salvaterra, R., Tiengo, A. et al. (2015). The EXTraS Project: Exploring the X-ray Transient and variable Sky. In "Swift: 10 yr of discovery", to appear in PoS
4. Feng, H. and Soria, R. (2011). Ultraluminous X-ray sources in the Chandra and XMM-Newton era. New Astron. Rev. 55, 166
5. Pietsch, W. and Haberl, F. (2005). XMM-Newton detection of type I X-ray bursts in M31. A&A 430, 25
6. Mereghetti, S. (2008). The strongest cosmic magnets: soft gamma-ray repeaters and anomalous X-ray pulsars. A&ARv, 15, 225
7. Merloni, A., Predehl, P., Becker, W. et al. (2012). eROSITA Science Book: Mapping the Structure of the Energetic Universe. arXiv:1209.3114
8. Rosen, S., Webb, N. A., Watson, M. G. et al. (2015). The XMM-Newton serendipitous survey. VII. The third XMM-Newton serendipitous source catalogue. submitted to A&A, arXiv:1504.07051
9. Sidoli, L. (2011). Latest progress on supergiant fast X-ray transients and future direction. Adv.Sp.Res. 48, 88
10. Soderberg, A. M., Berger, E., Page, K. L. et al. (2008). An extremely luminous X-ray outburst at the birth of a supernova. Nature 453, 69
11. Strohmayer, T. and Bildsten, L. (2010). New views of thermonuclear bursts. In Compact stellar X-ray sources, ed. Lewin, W.H.G. and van der Klis, M., pp 113–156 Cambridge: CUP.
12. Strüder, L., Briel, U., Dennerl, K. et al. (2001). The European Photon Imaging Camera on XMM-Newton: The pn-CCD camera. A&A 365, L18
13. Thornton, D., Stappers, B., Bailes, M. et al. (2013). A Population of Fast Radio Bursts at Cosmological Distances. Science 341, 53
14. Turner, M. J. L., Abbey, A., Arnaud, M. et al. (2001). The European Photon Imaging Camera on XMM-Newton: the MOS cameras. A&A 365 , L27